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Are shocks to disaggregated energy consumption in Malaysia permanent or temporary? Evidence from LM unit root tests with structural breaks

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ABSTRACT

The objective of this paper is to examine whether energy consumption in Malaysia, disaggregated by sector and type, is stationary or contains a unit root. To realize our objective we apply the Lagrange multiplier (LM) family of unit root tests with up to two structural breaks. Depending on the decision rule for selecting between results in the no-break, one-break and two-break cases, we find that energy consumption is stationary for between 50 per cent and 70 per cent of the disaggregated energy series and between 25 per cent and 50 per cent of sectors. Implications for the Malaysian government's attempts to reduce fossil fuel consumption are discussed.

Contents

1. Introduction

Beginning with Narayan and Smyth [1] a sizeable literature has developed around testing for a unit root in energy consumption. A recent survey article identified 32 related studies that have been published since 2007 [2]. That survey article also pointed to gaps in the extant literature on testing for a unit root in energy consumption or production and offered suggestions for future research. Among the major gaps identified in the survey article was the lack of single country studies for countries other than the United States, which (a) consider the integration properties of disaggregated energy consumption; and (b) consider whether the integration properties of energy consumption vary according to sector.

The need for further detailed studies of the integration properties of disaggregated energy consumption is particularly true for developing countries. The International Energy Agency predicts that there will be a 53 per cent increase in global energy consumption by 2030 and that 70 per cent of the increase in energy consumption will occur in the developing world [3]. However, the relative intensities with which different countries, and sectors within specific countries, consume energy will vary according to energy type. Aggregate energy consumption does not give an indication of the relative intensities with which different energy types are employed or how energy consumption varies across sectors [4]. In terms of testing for a unit root in energy consumption, it is important to take account of heterogeneity in energy consumption because some forms of energy are more

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volatile than the others and some end consumers are larger than the others. If energy consumption is stationary, shocks to energy consumption will have temporary effects, but if energy consumption contains a unit root, shocks to energy consumption will be permanent [1,2]. This, in turn, has implications for the efficacy of policies designed to curtail fossil fuel consumption. If fossil fuel consumption contains a unit root, policies designed to curtail consumption will be effective because such policies will push consumption below its long-run trend path in the absence of such policies [2]. The extent of consumption in a sector and volatility in consumption will influence the extent to which shocks to energy consumption will result in deviations from the long-run equilibrium, the level of persistence following a shock and, thus, whether there is a unit root or not [5].

The need for further detailed single country studies is reinforced by the fact that there is no clear consensus about the integration properties of various types of disaggregated energy [5–20], nor the sectors in which energy is likely to be stationary [17,21,22]. This paper responds to the call for further detailed single country studies which consider the integration properties of disaggregated energy, and whether the integration properties differ by sector, by exploring this issue for Malaysia.

A feature of the study is that we use final energy demand, rather than final energy consumption. Final energy demand is the final energy consumption plus transmission and distribution (T&D) losses [23]. We consider final energy demand a better measure than energy consumption. While T&D losses can be sizeable, apart from technical losses, all energy generated contributes to economic growth [24]. Electric power T&D losses include losses in transmission between sources of supply and points of distribution to consumers including meter tampering, meter malfunction, billing irregularities, illegal connections and unpaid bills [25]. In most of the ASEAN countries, including Malaysia, electro-mechanical induction electricity meters, which are readily susceptible to tampering, are employed [25]. However, the most common form of non-technical losses occurs via illegal direct connection to power lines, especially by street vendors and in shanty towns [25]. Since 1970 annual electric power T&D losses, as a percentage of output, have varied from a low of 1.3 per cent to 12.1 per cent. In several years; namely, 1974, 1976, 1993 and 1996, T&D losses have exceeded 10 per cent [26]. In the 1990s power theft in Malaysia was responsible for annual losses of RM500 million ($US 165 million) [27]. More recently, in 2004, Malaysia's largest electricity supplier – Tenaga Nasional Berhad (TNB) – recorded losses of RM800 ($US265 million) due to non-technical losses [25].

2. The Malaysian context

Since the mid 1980s Malaysia has enjoyed high rates of economic growth accompanied by high-energy consumption. In 1985 the Malaysian government implemented the Industrialization Plan, which has resulted in a structural shift from an agricultural-based to a manufacturing and service-based economy [28]. The industrial sector now accounts for 48.1 per cent of Gross Domestic Product (GDP), the service sector accounts for 43.6 per cent and agriculture accounts for 8.3 per cent [29]. Over the last two decades, growth in Malaysia's GDP has averaged 6 per cent [30]. Between 1990 and 2005 total primary energy consumption increased from 19.6 million tons of oil equivalent (Mtoe) to 60.4 Mtoe [31].

However, to say that high economic growth has been accompanied by an increase in energy consumption masks significant changes in the energy mix over time. The major energy source in Malaysia at the beginning of the 1980s was oil. In 1981 the Malaysian government introduced the four-fuel diversification strategy, which has seen consumption of oil fall with a commensurate increase in consumption of natural gas. Consumption of coal has also increased, primarily as a result of moves by the Malaysian government to reduce the dependence of power generation on natural gas [30]. Table 1 shows the change in the energy mix in Malaysia since 1980. In 1980, oil/diesel accounted for 87.9 per cent of energy consumption, while coal and natural gas accounted for just 0.5 per cent and 7.5 per cent respectively. By 2010, consumption of oil/diesel had dropped to a miniscule 0.2 per cent of total energy consumption, while consumption of natural gas (55.9 per cent) and coal (36.5 per cent) together accounted for over 90 per cent of total energy consumption. Electricity is largely dependent on fossil-fuels. About 95 per cent of electricity generation comes from fossil fuels with coal alone responsible for about 30 per cent in 2009 [38].

There is also a considerable variation in energy consumption by sector. Table 2 shows variation in primary energy demand by sector since 1980. The transport sector is the largest consumer of energy at just over 40 per cent of total consumption. The industrial sector is the second largest consumer of energy at just under 40 per cent of total consumption. By comparison, residential and commercial (around 13 per cent) and non-energy consumption (6–7 per cent) have been relatively low.

Over the next two decades, energy demand is expected to grow at 5 per cent per annum [33]. Most of this growth is expected to be due to high demand in the manufacturing and transport sectors. The transport sector is expected to be a major driver as continued increases in living standards generate further increases in car ownership [34]. The industrial sector will be an important consumer of energy because Malaysia's Vision 2020 suggests that it

Table 1
Energy mix in Malaysia (percentage).
Source: Oh et al. [3].

Source	1980	1990	2000	2005	2010
Oil/diesel	87.9	71.4	4.2	2.2	0.2
Natural gas	7.5	15.7	77.0	70.2	55.9
Hydro	4.1	5.3	10.0	5.5	5.6
Coal	0.5	7.6	8.8	21.8	36.5
Biomass	–	–	–	0.3	1.8

Table 2
Primary energy demand by sector.
Source: Rahmin and Liwan [32].

Source	2000 (Per cent)	2005 (Per cent)	2010 (Per cent)	Average annual growth rate	
				8MP	9MP
Transport	40.6	40.5	41.1	5.5	6.6
Industrial (a)	38.4	38.6	38.8	5.7	6.4
Residential and Commercial	13.0	13.1	12.8	5.6	6.0
Non-energy (b)	7.6	7.3	6.5	4.7	4.0
Agriculture and Forestry	0.4	0.5	0.8	12.9	15.9
Total (c)	1243.7	1631.7	2217.9	5.6	6.3
Per capita consumption	52.9	62.2	76.5	3.3	4.2

(a) Includes manufacturing, construction and mining.
(b) Includes natural gas, asphalt, bitumen, industrial feedstock and grease, lubricants.
(c) Total demand in petajoules.

will be central to promoting economic growth [34]. In terms of energy type, over the next two decades gas is projected to increase 6.3 per cent, electricity 5.3 per cent, oil 4.7 per cent, coal 2.8 per cent and other fuels 1.5 per cent [35]. To the extent that Malaysia becomes over-reliant on coal or natural gas, it is expected to build more coal-fired plants [33].

Malaysia's reliance on fossil fuel consumption has raised serious concerns about its effect on the environment. Malaysia is among the largest emitters of greenhouse gas emissions in the world. Between 1990 and 2006 Malaysia's compounded average growth rate in greenhouse gas emissions was 7.9 per cent [36]. Between 2005 and 2020, Malaysia's greenhouse gas emissions are expected to increase 74 per cent from 189 million tonnes of CO2e to 382 million tonnes of CO2e [36]. At the Copenhagen Climate Change Conference in 2009, relative to 2005 levels, Malaysia conditionally agreed to reduce greenhouse gas emissions, as a proportion of GDP, by up to 40 per cent by 2020. The Ninth Malaysian Plan (2006–2010) focused attention on the sustainable development of the energy sector and a move away from fossil fuels. In 2009 the Malaysian government introduced a National Green Technology Policy. A number of policies have been implemented to reduce reliance on fossil fuels. While biomass and hydro constitute a relatively small part of Malaysia's energy mix (see Table 1), several policies designed to reduce fossil fuel consumption in the energy mix are being discussed and/or implemented. Many of these policies are discussed in Refs. [3,29–30,33–39]. Whether these policies will be effective will depend on whether the various energy types are stationary or not. To be effective in reducing fossil fuel consumption, a negative shock to the long-run growth path needs to have a permanent effect on consumption (i.e. there needs to be a unit root in energy consumption).

3. Data and methodology

Our data is final energy demand by fuel type and final energy demand by sector, both measured in ktoe. There are 10 fuel types i.e diesel, fuel oil, motor petrol, liquefied petroleum gas (LPG), kerosene, aviation turbine fuel and aviation gasoline (ATF and AV gas), non-energy, natural gas, coal and coke and electricity in this study. The four sectors are industrial, transport, non-energy and residential and commercial. All data are sourced from the Malaysia Energy Information Hub (MEIH) [40]. According to the definition in MEIH, ATF is used as a fuel in aviation gas turbines mainly refined from kerosene and AV gas is a special blended grade of gasoline used in aircraft engines of the piston type. Non-energy products refer mainly to naphtha, bitumen and lubricants, which are obtained by the refinery process from petroleum but used for non-energy purposes. The sample and time period is annual data from 1978 to 2010. Figs. 1 and 2 present time series plots for all the energy variables employed in the study.

To test for a unit root we implement the Lagrange multiplier (LM) unit root test with zero, one and two structural breaks proposed by Schmidt and Phillips [41] and Lee and Strazicich [42]. We first allow for one break in the intercept (Model A) and intercept and trend (Model C) and then proceed to allow for two breaks in the intercept (Model AA) and intercept and trend (Model CC). One advantage of employing the LM family of tests is that it has been shown to have better properties than the one and two-break ADF-type test proposed by Zivot and Andrews [43] and Lumsdaine and Papell [44] (see [42]). A second advantage of using the LM family of tests is that the one and two-break case have been frequently used in the literature (see [8, 11, 19, 21,22, 45–49). Thus, using the LM family of unit root tests assists in comparing results with findings from previous studies. We do not reproduce the

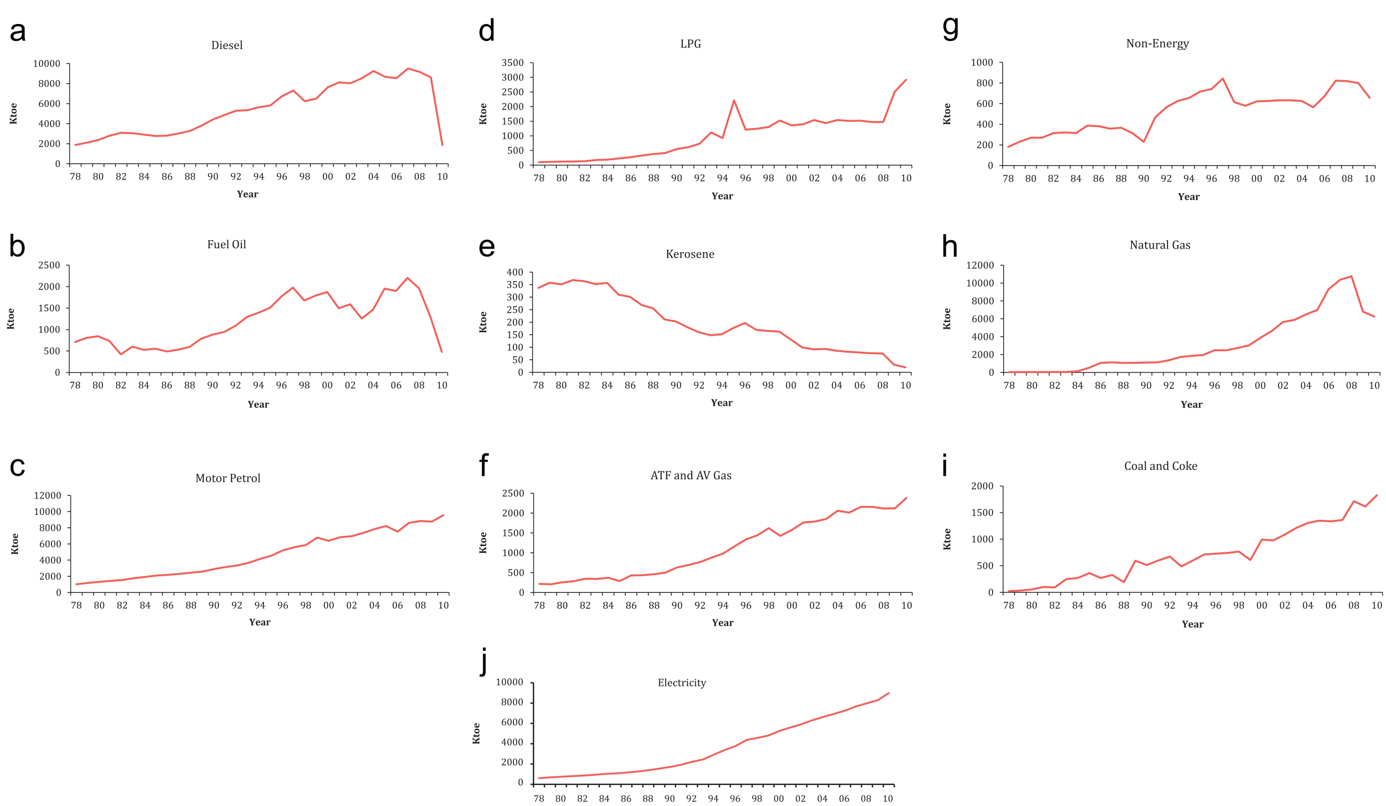

Fig. 1. (a) Time series plot for final energy demand by diesel. (b) Time series plot for final energy demand by fuel oil. (c) Time series plot for final energy demand by motor petrol. (d) Time series plot for final energy demand by LPG. (e) Time series plot for final energy demand by kerosene. (f) Time series plot for final energy demand by ATF and AV gas. (g) Time series plot for final energy demand by non-energy. (h) Time series plot for final energy demand by natural gas. (i) Time series plot for final energy demand by coal and coke. (j) Time series plot for final energy demand by electricity.

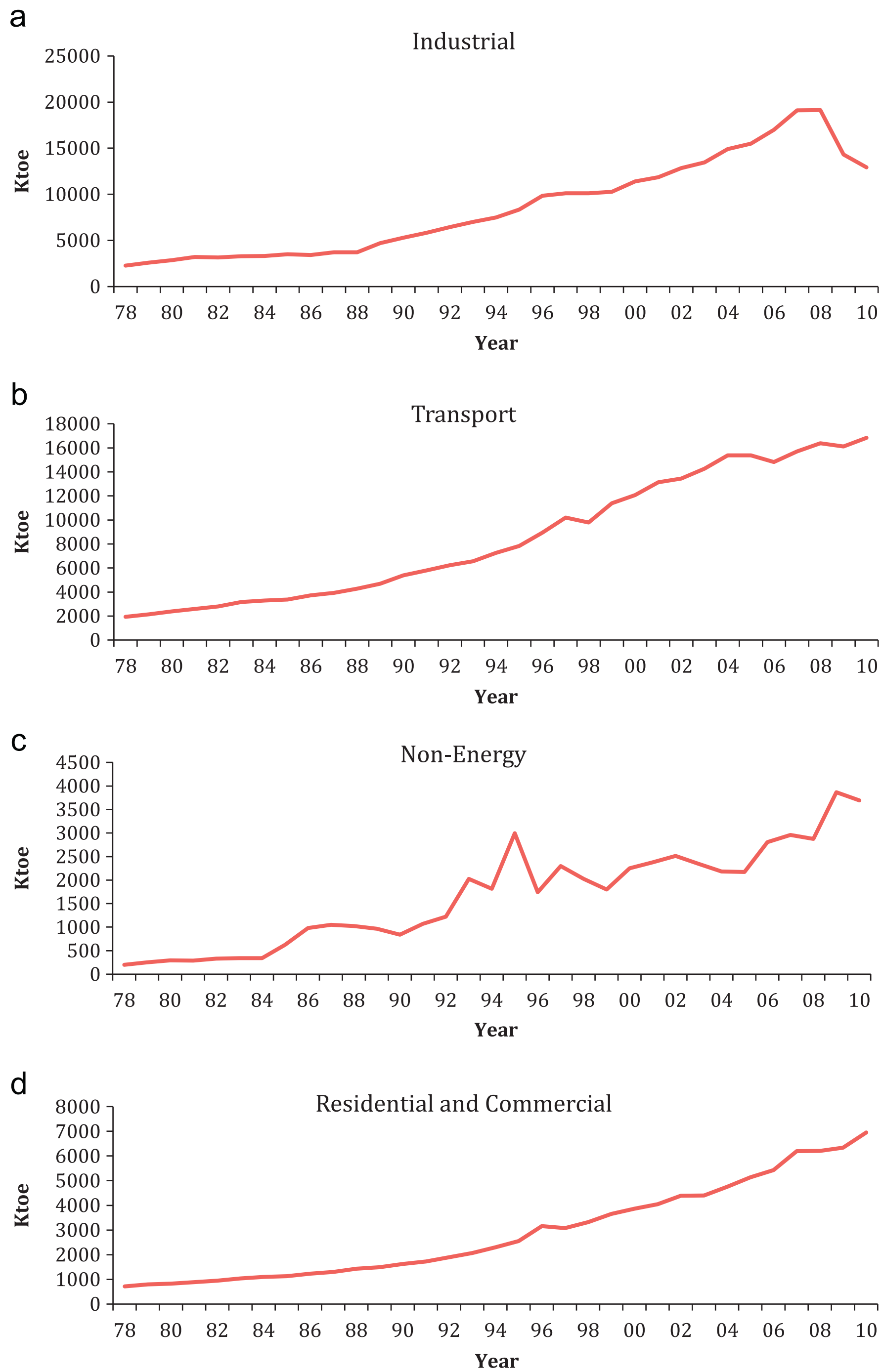

Fig. 2. (a) Time series plots for final energy demand by industrial sector. (b) Time series plots for final energy demand by transport sector. (c) Time series plots for final energy demand by non-energy sector. (d) Time series plots for final energy demand by residential and commercial sector.

detailed equations behind the LM family of unit root tests, given that the tests have been widely used and are well known. We refer the interested reader either to the original papers [41,42] or the previous studies to have employed the tests.

4. Results

Table 3 contains the findings for the two Schmidt and Phillips [41] test statistics; namely, $Z(\rho)$ and $Z(\tau)$. We fail to reject the null hypothesis of a unit root for each energy type as well as each of the four sectors considered at all lags. Thus, the Schmidt and Phillips [41] LM unit root results unanimously suggest that shocks to disaggregated energy by type and sector will have permanent effects on consumption.

The limitation of the Schmidt and Phillips [41] LM unit root is that it does not account for potential structural breaks in the series. The presence of structural breaks in the time series reduces the power to reject the unit root null [50]. To address this issue, we first allow for one break in the LM unit root test. Table 4 presents the results for Lee and Strazicich's [25] Model A, which allows for one break in the intercept. The results for Lee and Strazicich's [25] Model C, which accommodates one break in the intercept and slope, are presented in Table 5.

Beginning with the results in Table 4, there is slightly more evidence of stationarity for disaggregated energy as the LM test

Table 3
Results of LM Test with no break (Schmidt and Phillips [41]).

Lag➡	0		1		2		3		4	
	$Z(\rho)$	$Z(\tau)$	$Z(\rho)$	$Z(\tau)$	$Z(\rho)$	$Z(\tau)$	$Z(\rho)$	$Z(\tau)$	$Z(\rho)$	$Z(\tau)$
Energy demand by fuel type										
Diesel	−5.3889	−1.6867	−5.7294	−1.7392	−5.8828	−1.7623	−5.8191	−1.7528	−5.8169	−1.7525
Fuel oil	−3.1849	−1.2738	−3.7597	−1.3839	−4.1447	−1.4531	−4.2443	−1.4704	−4.2807	−1.4767
Motor petrol	−4.2513	−1.4843	−4.2366	−1.4817	−4.8073	−1.5784	−5.6853	−1.7165	−6.3889	−1.8196
LPG	−7.0435	−1.9553	−5.0207	−1.6508	−5.9010	−1.7897	−6.4030	−1.8642	−6.9724	−1.9454
Kerosene	−6.0549	−1.7978	−7.9319	−2.0577	−8.2150	−2.0941	−8.1286	−2.0831	−7.9392	−2.0587
ATF and AV Gas	−6.5888	−1.8838	−5.0855	−1.6550	−5.6453	−1.7437	−5.6104	−1.7383	−6.2719	−1.8380
Non-energy	−12.1522	−2.6873	−13.5303	−2.8356	−13.5393	−2.8365	−13.6413	−2.8472	−13.4244	−2.8245
Natural gas	−3.4576	−1.3301	−5.4024	−1.6626	−6.1656	−1.7761	−6.2069	−1.7821	−5.9765	−1.7487
Coal and coke	−6.5632	−1.8798	−4.9973	−1.6403	−6.2475	−1.8340	−6.7325	−1.9039	−7.3900	−1.9947
Electricity	−1.2829	−0.7964	−2.0229	−1.0001	−2.6998	−1.1554	−3.3592	−1.2888	−3.8477	−1.3793
Energy demand by sectors										
Industrial	−3.8594	−1.4098	−5.2309	−1.6413	−5.7564	−1.7217	−5.7295	−1.7177	−5.7674	−1.7234
Transport	−3.2927	−1.2963	−3.5206	−1.3404	−3.8740	−1.4060	−4.4547	−1.5077	−5.0722	−1.6088
Non-energy	−8.2122	−2.1325	−7.2793	−2.0077	−8.5370	−2.1743	−8.4562	−2.1639	−8.1057	−2.1186
Residential and commercial	−8.0864	−2.1138	−7.1356	−1.9856	−7.2500	−2.0015	−7.8902	−2.0880	−8.3448	−2.1473

Note: Critical value determination is based on Schmidt and Phillips [[41], Tables 1A and B].

Table 4
Results of LM test with one break (Lee and Strazicich, [42]) – Model A.

Series	TB	K	S_{t-1}	B_t
Energy demand by fuel type				
Diesel	1988	0	−0.1788 (−1.7725)	0.0951 (0.3435)
Fuel oil	2001	1	−0.1139 (−1.4998)	0.2343 (0.9034)
Motor petrol	1999	4	−0.2883 (−2.4940)	−0.1048** (−2.3471)
LPG	1998	3	−0.4835** (−3.6469)	0.9634*** (3.0782)
Kerosene	1997	1	−0.2538 (−2.2835)	0.1855 (1.0963)
ATF and AV gas	1985	2	−0.2362 (−2.4042)	0.2894** (2.6819)
Non-energy	1991	0	−0.4519 (−3.0565)	0.2290 (1.4231)
Natural gas	1984	2	−0.3305 (−3.0164)	1.0327*** (3.2557)
Coal and coke	1984	0	−0.2354 (−2.0663)	0.3698 (1.1067)
Electricity	2000	4	−0.1482** (−4.0162)	0.0774*** (2.8116)
Energy demand by sectors				
Industrial	1992	4	−0.1859 (−2.0315)	−0.0877 (−0.8850)
Transport	1992	4	−0.1495 (−1.7065)	−0.0505 (−1.1253)
Non-energy	1997	2	−0.3938 (−2.5487)	0.1420 (0.5700)
Residential and commercial	1995	0	−0.4857 (−3.2036)	0.1981*** (5.6382)

Notes: The test statistic is S_{t-1}, B_t is the break point in the intercept, k is the lag length and TB is the break date. The *t*-values are presented in parenthesis. Critical values for the LM test at 10 per cent, 5 per cent and 1 per cent significant levels = −3.211, −3.566, −4.239. * (**) *** denote statistical significance at the 10 per cent, 5 per cent and 1 per cent levels respectively.

with one break in the intercept rejects the unit root null for electricity and LPG at the 5 per cent level. However, the results presented in Table 4 are consistent with those in Table 3 in suggesting that energy demand in each of the sectors is non-stationary. Turning to the results in Table 5, there is more evidence of stationarity by energy type and sector. The LM unit root test, with one break in the intercept and slope, rejects the unit root null for seven of the ten energy types at 5 per cent or better (diesel, motor petrol, LPG, kerosene, natural gas, coal and coke and electricity) and a further energy type (ATF and AV gas) at the 10 per cent level. Model C also rejects the unit root null for three of the four sectors at the 5 per cent level or better (industrial, non-energy and transport) and the fourth sector (residential and commercial) at the 10 per cent level.

A natural question to ask is that given the findings from Models A and C and the no-break case differ, which is to be preferred? Evidence from the Monte Carlo simulations suggests that Model C has better properties than Model A [51,52]. Model C also has the advantage over Model A that it is more general as it allows for a potential structural break in the slope. Thus, between Models A and C, the findings from Model C are to be preferred. When comparing the results for Model C with the no-break case, it is to be remembered that allowing for a structural break will not necessarily result in more rejections because the absolute value of the critical values also increase [53]. A rule of thumb, employed in previous studies, is that in cases in which the no-break and one-break Model C cases differ, the results of Model C should be preferred if the breaks in the intercept and slope are significant (see e.g. [54,55]). Of the disaggregated energy series for which Model C rejects the unit root null, this is the case for motor petrol, LPG, coal and coke and electricity. Of the four sectors, this is the case for non-energy. Hence, on the basis of a comparison of the no-break case, Models A and C, we conclude that the unit root null is rejected for four disaggregated energy series (motor petrol, LPG, coal and coke and electricity) and only one sector; namely, non-energy. Even after allowing for one break, there is still considerable evidence that shocks to energy consumption will have permanent effects.

Thus far, we have accommodated one structural break in the time series. We have found evidence of stationarity in 40 per cent of the energy series and 25 per cent of sectors at the 5 per cent level or better. It may be that in allowing for a second structural break, we can find evidence of stationarity in the remaining series at the 5 per cent level or better. To this end, we report results for the LM unit root with two breaks in the intercept (Model AA) in Table 6 and the LM unit root test with two breaks in the intercept and slope

Table 5
Results of LM test with one break (Lee and Strazicich, [42]) – Model C.

Series	TB	k	S_{t-1}	B_t	D_t
Energy demand by fuel type					
Diesel	2004	2	−1.4312***	−0.1928	−0.0592
			(−6.7496)	(−0.9772)	(−0.4862)
Fuel oil	1998	2	−0.4552	0.0935	0.1367
			(−3.6160)	(0.4059)	(1.1184)
Motor petrol	2004	4	−1.0772***	0.1010**	−0.1916***
			(−5.1303)	(2.5419)	(−5.5032)
LPG	1994	1	−0.8522**	1.4038***	−0.4804***
			(−4.5350)	(7.1576)	(−5.1378)
Kerosene	2001	4	−1.3917***	−0.0620	0.0485
			(−5.7357)	(−0.4307)	(0.8357)
ATF and AV gas	1996	0	−0.7136*	0.0299	0.0322
			(−4.2133)	(0.3342)	(0.8325)
Non-energy	2000	3	−0.9431	0.1156	−0.2206***
			(−3.7892)	(0.6596)	(−2.8244)
Natural gas	1988	1	−0.4309**	0.1081	0.0146
			(−4.5973)	(0.5036)	(0.1407)
Coal and coke	1985	0	−1.1056***	−0.5097**	−0.2840***
			(−6.2892)	(−2.4851)	(−3.3017)
Electricity	1992	3	−0.3161***	−0.0442*	0.0344**
			(−5.1862)	(−1.9023)	(2.4475)
Energy demand by sectors					
Industrial	2000	4	−0.7485**	−0.0403	0.0657*
			(−4.6022)	(−0.5864)	(1.7988)
Transport	1997	4	−0.6380**	−0.1590***	0.0309
			(−4.6816)	(−4.4720)	(1.4844)
Non-energy	1993	3	−1.4362***	−0.2965*	−0.1276**
			(−5.3964)	(−1.7810)	(−2.1820)
Residential and commercial	1994	0	−0.7059*	0.0050	0.0463**
			(−4.1781)	(0.1361)	(2.6122)

Critical values

Location of break, λ	0.1	0.2	0.3	0.4	0.5
1 Per cent significance level	−5.11	−5.07	−5.15	−5.05	−5.11
5 Per cent significance level	−4.50	−4.47	−4.45	−4.50	−4.51
10 Per cent significance level	−4.21	−4.20	−4.18	−4.18	−4.17

Notes: In addition to the notes in Table 4, D_t is the break in the slope. The critical values are symmetric around λ and $(1-\lambda)$.

Table 6
Results of LM test with two breaks (Lee and Strazicich, [42]) Model AA.

Series	TB_1	TB_2	k	S_{t-1}	B_{t1}	B_{t2}
Energy demand by fuel type						
Diesel	1988	2007	0	−0.1955	0.0930	0.0953
				(−1.7415)	(0.3155)	(0.3160)
Fuel oil	1998	2001	1	−0.1249	0.2476	0.2517
				(−1.4777)	(0.8851)	(0.8952)
Motor petrol	1989	1999	4	−0.3441	0.0571	−0.1014*
				(−2.4193)	(1.2473)	(−2.0107)
LPG	1998	2006	3	−0.5385*	1.0856***	−0.0.2585
				(−3.7321)	(3.2248)	(−1.3175)
Kerosene	1993	1997	1	−0.2878	0.0924	0.1832
				(−2.1928)	(0.5165)	(1.0010)
ATF and AV gas	1985	2000	2	−0.2892	0.2734**	0.2026**
				(−2.7196)	(2.4298)	(2.0619)
Non-energy	1991	1997	0	−0.5669	0.1739	−0.2393
				(−3.3280)	(1.1335)	(−1.5187)
Natural gas	1988	1991	1	−0.1965	0.1712	0.2335
				(−2.8226)	(0.6251)	(0.8729)
Coal and coke	1984	1998	0	−0.2866	0.3935	−0.4525
				(−2.1640)	(1.1305)	(−1.3664)
Electricity	1984	2000	4	−0.1516*	−0.0451	0.0823**
				(−3.7202)	(−1.9983)	(2.7167)
Energy demand by sectors						
Industrial	1987	1989	1	−0.1815	−0.1126	−0.0460
				(−1.9430)	(−1.2764)	(−0.4976)
Transport	1989	1997	3	−0.1363	0.0682	−0.1192**
				(−1.7155)	(1.6622)	(−2.7301)
Non-energy	1984	2003	0	−0.5342	0.4542**	−0.2731
				(−3.1943)	(2.3613)	(−1.4003)
Residential and commercial	1993	1995	0	−0.6637*	0.0738**	0.2074***
				(−3.7292)	(2.3087)	(5.9870)

Notes: In addition to the notes in Table 4, TB_1 and TB_2 are the dates of the structural breaks; B_{t1} and B_{t2} are the dummy variables for the structural breaks in the intercept.

(Model CC) in Table 7. We begin with the results for Model AA in Table 6. There is little further evidence of stationarity compared with the findings for Model A in Table 4. The unit root null continues to be rejected for electricity and LPG, but this time only at 10 per cent. The only sector for which the unit root null is rejected is commercial and residential and again only at the 10 per cent level.

We now turn to the results for Model CC presented in Table 7. The unit root null is rejected for 70 per cent of the disaggregated energy series at the 5 per cent level or better (diesel, fuel oil, LPG, ATF and AV gas, natural gas, coal and coke and electricity). However, the unit root null is only rejected for two of the four sectors (non-energy and residential and commercial) and only at the 10 per cent level.

How do we decide which of these alternative sets of findings is more reliable? First, we compare Models CC and AA, given that Model CC provides more evidence of stationarity. In contrast to the one break case, there is no Monte Carlo evidence on which model is preferable in a statistical sense. However, as in Model A versus Model C, it remains that Model CC is more general as it allows for two potential breaks in the slope. Hence, we prefer Model CC over Model AA. This is consistent with the approach taken in previous studies (see e.g. [19]).

Next we compare Model CC with Model C and the no-break case. The no-break case fails to reject the unit root null for each energy series and sector. While both Models C and CC suggest that the unit root null is rejected for 70 per cent of the disaggregated energy series at 5 per cent or better, the models differ across some specific energy types. To be specific, the unit root null hypothesis is rejected for fuel oil in Model CC, but not Model C, while the unit root null is rejected for motor petrol and kerosene in Model C, but not Model CC. Finally, while both Models C and CC reject the unit root null in ATF and AV gas, in Model CC it is rejected at 5 per cent and in Model C it is rejected at 10 per cent. Thus, at the 5 per cent level or better, Models C and CC differ on four series (fuel oil, motor petrol, kerosene and ATF and AV gas). The results for Models C and CC also differ for 75 per cent of the sectors (industrial, transport and non-energy) at the 5 per cent level or better.

As discussed above, we prefer Model C to the no-break case if the break in the intercept and slope are significant. We prefer Model CC to the hybrid results based on this selection rule if the second break in the intercept and slope are significant. This again follows the rule of thumb employed in previous studies (see e.g. [54,55]).

Using this selection rule, we summarize a set of preferred results across the no-break case, Models C and CC in the second column of Table 8 (titled ‘rule of thumb requiring break in the intercept and slope’). Overall, we reject the unit root null for 50 per cent of the disaggregated energy series (motor petrol, LPG, ATF and AV gas, coal and coke and electricity) and for one sector (non-energy).

Table 7
Results of LM Test with two breaks (Lee and Strazicich, [42]) – Model CC.

Series	TB_1	TB_2	k	S_{t-1}	B_{t1}	B_{t2}	D_{t1}	D_{t2}
Energy demand by fuel type								
Diesel	1999	2004	2	−1.5975***	0.4900**	−0.2197	−0.1586	0.0385
				(−6.6137)	(2.2212)	(−1.0396)	(−1.6733)	(0.2426)
Fuel oil	1986	1999	4	−1.3370***	−0.5511***	0.2188	0.0750	−0.1254*
				(−6.5808)	(−2.8175)	(1.2386)	(0.8195)	(−1.7203)
Motor petrol	1986	1996	0	−1.0126	0.0112	0.0130	−0.1062***	0.0157
				(−5.1635)	(0.2830)	(0.3406)	(−4.0159)	(0.7741)
LPG	1992	2007	0	−1.2394***	0.2921*	−0.4583**	0.1402**	0.3273***
				(−6.5088)	(1.9894)	(−2.6424)	(2.1001)	(3.0739)
Kerosene	1991	2001	4	−1.4879	−0.1400	−0.0521	−0.0578	0.1076
				(−5.0001)	(−0.8994)	(−0.3030)	(−0.8385)	(1.3024)
ATF and AV gas	1987	1997	2	−1.9413**	−0.3085***	0.1683**	0.0237	−0.1749***
				(−6.1189)	(−3.4614)	(2.4542)	(0.7295)	(−5.7230)
Non-energy	1987	1992	1	−1.1860	0.2759	−0.0006	−0.4591***	0.2516**
				(−5.1452)	(1.6263)	(−0.0039)	(−3.5444)	(2.4574)
Natural gas	1987	2004	4	−2.2970**	−0.7735**	−0.2475	1.1796***	0.4940***
				(−6.1639)	(−2.6701)	(−1.4585)	(4.2397)	(4.1419)
Coal and coke	1986	1992	4	−2.9089***	0.6211**	−0.8988***	−1.4342***	0.0550
				(−8.3097)	(2.3795)	(−3.6690)	(−7.1784)	(0.5543)
Electricity	1985	1997	4	−0.7713**	−0.0042	−0.0593***	−0.0085	−0.0234**
				(−5.6690)	(−0.2577)	(−3.0354)	(−0.6360)	(−2.3050)
Energy demand by sectors								
Industrial	1992	2000	4	−1.0245	−0.2343**	−0.0393	0.0218	0.0882**
				(−5.3077)	(−2.7230)	(−0.5477)	(0.6330)	(2.1454)
Transport	1985	1999	4	−1.9587	0.0652	−0.1191**	−0.0999***	0.0368*
				(−5.2136)	(1.6988)	(−2.3882)	(−3.2562)	(1.7396)
Non-energy	1993	2001	3	−1.7475*	−0.4813**	0.1019	0.0035	−0.1922**
				(−5.5857)	(−2.5016)	(0.5856)	(0.0443)	(−2.1345)
Residential and commercial	1991	1997	0	−1.0921*	−0.0314	0.0018	0.0458**	−0.0516***
				(−5.5925)	(−0.9121)	(0.0548)	(2.7546)	(−3.0689)
Critical values for the LM test								

λ_2		0.4			0.6			0.8	
λ_1	1 per cent	5 per cent	10 per cent	1 per cent	5 per cent	10 per cent	1 per cent	5 per cent	10 per cent
0.2	−6.16	−5.59	−5.27	−6.41	−5.74	−5.32	−6.33	−5.71	−5.33
0.4	–	–	–	−6.45	−5.67	−5.31	−6.42	−5.65	−5.32
0.6	–	–	–	–	–	–	−6.32	−5.73	−5.32

Notes: In addition to the notes in Tables 4 and 6, D_{t1} and D_{t2} are the dummy variables for the structural breaks in the slope. λ_j denotes the location of breaks.

Table 8
Preferred results based on comparing the no-break case with Models C and CC.

Series	Unit root null rejected?	
	Rule of thumb requiring break in the intercept *and* slope	Rule of thumb requiring break in the intercept *or* slope
Energy type		
Diesel	No	No
Fuel oil	No	Yes
Motor petrol	Yes	Yes
LPG	Yes	Yes
Kerosene	No	No
ATF and AV gas	Yes	Yes
Non-energy	No	No
Natural gas	No	Yes
Coal and coke	Yes	Yes
Electricity	Yes	Yes
Sector		
Industrial	No	No
Transport	No	No
Non-energy	Yes	Yes (10 per cent)
Residential and commercial	No	Yes (10 per cent)

One might argue that a rule of thumb that requires both the break in the intercept and slope to be significant is too strict. Thus, we also compare the no-break case, one break and two break cases only requiring the break in the intercept or slope to be significant. Thus, comparing Model C with the no-break case, with this rule of thumb we prefer the results of Model C if the break in the intercept or slope is significant. Comparing Models CC and C, the rule of thumb is that we prefer Model CC if the second break in the intercept or slope is significant. The results are reported in the second column of Table 8 (titled 'rule of thumb requiring break in the intercept or slope'). As one would expect, there is slightly more evidence of stationarity. We now reject the unit root null for 70 per cent of the disaggregated energy series (the same five with the stricter rule plus fuel oil and natural gas). We reject the unit root null for two of the four sectors (non-energy and residential and commercial), but only at 10 per cent.

What explains the different results across disaggregated energy types? One potential explanation is that those energy types of which a country has abundant resources are more likely to be stationary [56]. The reasoning is that if a country is rich in resources of a particular energy type it can maintain stability in consumption [57]. Malaysia is relatively rich in reserves of oil, mostly off Peninsular Malaysia. In 2012, it was ranked 24th in terms of world oil reserves [40]. In January 2012 Malaysia had oil reserves of 4 billion barrels, down from a peak of 4.6 billion barrels in 1996 [32,58]. Malaysia is also rich in natural gas, primarily in East Malaysia. Malaysia was ranked 12th in terms of world natural gas reserves in 2012 [32]. In January 2011, it had 83 trillion cubic feet of natural gas reserves [32]. In contrast, although there are some coal reserves in Malaysia, only a small fraction are being mined. While Malaysia is a net exporter of natural gas and oil, it is a net importer of coal [32,58].[1] Our results only provide, at best, mixed evidence that stationarity of disaggregated energy is related to reserves. Some crude oil distillates are stationary, but others are not. Natural gas is only stationary if one adopts the more relaxed rule of thumb for comparing the no-break case with Models C and CC. Meanwhile, coal and electricity, which are fueled by coal powered plants, were found to be stationary.

[1] Malaysia's reserves of oil have been declining since 2005. Malaysia may move from being a net exporter of oil to a net importer of oil in 2013–2015 [32,38], but this is outside the range of this study.

A second possible explanation is that stationarity is related to volatility in the series. The argument is that series which are more volatile will be more likely to exhibit a unit root because shocks, which generate volatility in the first place, will be more persistent [5–7,59]. There is a little support for this hypothesis. The most volatile fuel types are coal and coke, fuel oil and non-energy. Coal and coke are stationary, non-energy contains a unit root and for natural gas the conclusion depends on the rule of thumb employed. Among the sectors, the most volatile is non-energy and non-energy is the one sector for which the unit root null is clearly rejected.

A third possible explanation is that stationarity is related to average consumption. The hypothesis is that disaggregated energy types in which average consumption is high, and in sectors with high average consumption, there is more likely to be a unit root because shocks to consumption will result in larger deviations from the long-run trend path [56]. There is no real support for this hypothesis when it comes to disaggregated energy types. Some energy types with high-and-mid level consumption (electricity, motor petrol, LPG, ATF and AV gases and coal) are stationary, while energy types with low average consumption (kerosene and non-energy) contain a unit root. There is, however, more support for this hypothesis when it comes to sectors. The biggest energy consumers (industrial and transport) are clearly non-stationary, while for the smaller consumers – non-energy and possibly residential and commercial, depending on the rule of thumb employed – the unit root null hypothesis is rejected.

Overall, we conclude that none of these explanations can conclusively rationalize which series are non-stationary on their own. The most promising explanation seems to be that the stationarity of energy consumption by sector is related to its average consumption. This is similar to previous findings for the United States [5]. We agree with Hasanov and Telatar when they suggest that a combination of the above factors, or a subset of those factors, is needed to explain which series contain a unit root [57].

While considering the break dates we focus on our preferred models (Models C, CC). Most of the breaks occurred in the latter half of the 1980s and first half of the 1990s or the latter half of the 1990s and first half of the 2000s. Several of the structural breaks are broadly linked to periods of recessions and economic recovery. Periods of recession are associated with a slowdown in energy use and periods of recovery with a commensurate pick-up. Of relevance here is the global recession in the late 1980s, following the Wall Street stock market collapse; the global recession in the early 1990s; the Asian financial crisis and the global recession in the early 2000s.

The structural breaks in the first half of the 2000s are also likely to be due to Malaysia strengthening its commitment to renewable energy at the expense of fossil fuel consumption in this period. Examples are introduction of the Small Renewable Energy Program and Malaysia becoming a signatory of the Kyoto protocol in 2002. There are no breaks in the first half of the 1980s, associated with the four-fuel diversification strategy, and only one break after 2005, associated with decline in oil reserves, the promotion of renewable energy in the Ninth Five-Year Plan and the National Green Technology Policy as well as rising prices of petroleum-based products. This, though, likely reflects the timeframe of the study.

5. Conclusion

Overall, our results are consistent with the received wisdom that adding a structural break increases the power to reject the unit root null and results in finding a higher proportion of stationary cases (see the discussion in Ref. [2]). This is certainly true if one compares the no-break case to Model C, although our

results also indicate that the marginal returns in this respect of adding a second break are small.

Our results suggest that the unit root null can be rejected for between 50 per cent and 70 per cent of disaggregated energy types, depending on the rule of thumb for selecting between the results for the no-break case, Models C and CC. The implication is that the efficacy of government policies designed to induce negative shocks to consumption will vary according to energy types. Based on the stricter rule of thumb, requiring the breaks in intercept and slope to be significant, policies causing negative shocks to diesel, fuel oil, kerosene, natural gas and non-energy uses would displace consumption from the long-run growth path and be effective in bringing about long-term reductions. However, policies designed to generate reductions in motor petrol, LPG, ATF and AV gas, coal and coke and electricity would only result in short-run deviations from the long-run trend path and, thus be ineffective.

More promising, in terms of suggesting policies to reduce fossil fuel consumption, are the sector results. Our findings suggest that policies designed to reduce energy consumption in the industrial and transport sectors will have lasting effects. The results for the residential and commercial sector are less clear. Results, based on the strict rule of thumb, suggest that policies designed to reduce energy consumption in the residential and commercial sector will also be effective in inducing a long-term deviation from the trend path. The results, based on the more relaxed rule of thumb, suggest that deviations from the long-run trend path in the commercial and residential sector will only be temporary, but this result is only weakly significant.

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